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Anthropogenic factors and nutrient variability along the Coral Coast, Fiji.

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Abstract. Coral reefs the world over are being threatened by anthropogenic factors, one of the most significant being nutrient enrichment of the coastal waters. The Coral Coast region, in south-western Viti Levu, Fiji, has undergone very rapid development since the 1970s. Observations by local communities and the few sporadic studies conducted in the area have shown progressive degradation of the fringing reefs and deterioration of the water quality. In the present study, while water column nutrient concentrations showed high variability, averages over a long period of monitoring showed clear associations between anthropogenic effects and water quality. Nutrient concentrations were highly variable, and showed little association with season, but were strongly linked to rainfall. The results also indicated the clear influence of pulse (storm runoff related) events on the nutrient and fecal coliform concentrations in the water column. Control sites located furthest from human settlements and development generally recorded lower nutrient and coliform concentrations than impacted sites. The importance of creeks as major sources of nutrient and fecal coliform to coastal waters was clearly evident, and this highlighted the need to properly manage catchment activities. Recommendations are proposed for better management of nutrient sources on land for the protection of the water quality, and therefore promote healthier coral reef systems.

Key words: Anthropogenic, Nitrate, Phosphate, Coastal, Fiji.

Introduction

Coral reefs are being threatened by anthropogenic factors, one of the most significant being nutrient enrichment of the coastal waters. The Coral Coast region, in south-western Viti Levu, Fiji, is no exception to this threat. The region was once thriving with healthy coral reefs, thus the name 'Coral Coast' (Raj et al., 1981). Interestingly, Ryland in his presentation to the 4th International Coral Reef Symposium had said "...with the attractive features of reef and beach, high insolation, and moderate rainfall, the Coral Coast is developing as a premier tourist area" (Ryland, 1981). At the time, there were only a few hotels, and villages were smaller in number and size. The few studies at the time recorded high coral species diversity (Morton & Raj, 1980). However, since the 1970s, the region has undergone very rapid development. A review of aerial photographs from 1967 onwards showed a number of distinct changes: increased village sizes and house numbers; construction, diversion and expansion of the Queens Highway; construction and expansion of resorts (Warwick and Naviti resorts); reduced coastal vegetation and in more recent cases, complete removal of the coastal fringe, whether it be mangrove zone or other coastal flora (Fiji Lands Department Maps, reviewed 2006).

Despite the changes taking place along the Coral Coast, a few studies have been done to monitor the effects of such changes on the water quality in the coastal waters and the marine ecosystems therein. Observations by local communities, and the study by Mosley and Aalbersberg (2003) indicated a deterioration of the water quality and degradation of the fringing reefs. Clearly, there was a need to gather more information about the effects of anthropogenic-derived changes on the coastal water quality, especially nutrient concentrations. The aim of the present research was to try and establish a link between variability in the status of nutrient concentration in the coastal waters, and the extent of human impact on land and shoreline, and assess these against the status of the health of the fringing reefs of the Coral Coast. This paper reports the nutrient results, but due to space limitations the discussion of fringing reef health will not be included.

Material and Methods

Study region and locality on Viti Levu, Fiji

The study was conducted along the Coral Coast region in the south-western part of Viti Levu, the largest island in the Fiji Group (Fig. 1). The sampling area stretched from Namaqumaqua (177° 50'E, 18° 15'S) in the province of Serua to the east, and as far

as Korotogo (177° 32' E, 18° 10' S) in the province of Nadroga to the west, a total distance of about 35 km by road. The study sites represented unimpacted sites (control C), and impacted sites near villages (V) and resorts (R). The selection of water sampling sites was influenced by accessibility from the main road, distance from known nutrient sources, and approval for access and work from local resource owners and resort operators. A total of 13 control, 11 village and 12 resort sites were monitored during the research, but at different frequencies depending on logistical factors and approval for access to the site (Tamata, 2007).

The 'control' sites were selected based solely on distance from suspected nutrient sources, since there was no previous information on the nutrient status of the area (Vuki et al., 2000). For impacted areas, the water sampling sites were located in the middle of the village or resort. Creeks and rivers within the locality of a control, village or resort site were also sampled to assess influence of catchment activities on coastal water quality.

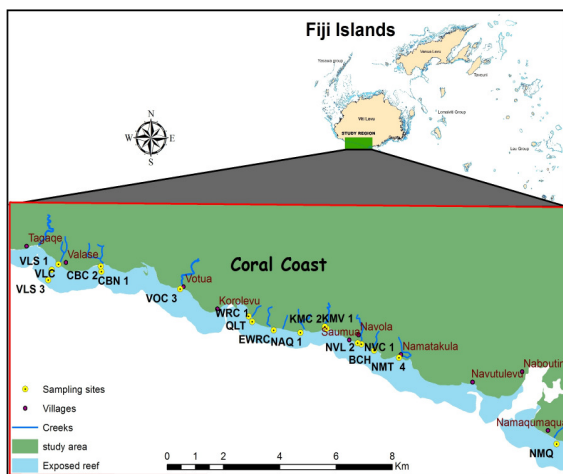


Figure 1: Locality Map for the Coral Coast Region, South-west Viti Levu, Fiji showing water sampling sites.

Nutrient analyses

Sampling was done from 2003-2006 during both the hot/wet (November to April), and the cool/dry seasons (May to October), as well as dry/wet weather conditions to assess seasonal and weather effects on water quality and nutrient levels of the coastal waters. As there were no weather stations within the area of study, the best approximation of rainfall was to use the standard measure of 25 mm/day as the guide. Dry weather was defined as those days with < 25 mm/day (or no rain in the 48 hours prior to sampling), and conversely, 'wet' days were defined as days on which > 25 mm/day fell in the area (or rain falling in the 48 hours prior to sampling). The Coral Coast being in the

drier part of Viti Levu, 18 of the 24 sampling events (75%) were dry weather events (Tamata, 2007).

Water quality was tested *in situ* with the Horiba Multimeter, surface water samples (3 replicates at each site) were also collected using standard procedures (Hansen and Koroleff, 1999). Collection of water samples was always carried out during outgoing tide, from approximately 2 hours after high tide during slack water. This was done to ensure that the samples contained any pollution originating from land-based sources, without any diluting effects of clean, oceanic water. Samples were filtered on site prior to transportation in coolers of ice to the University of the South Pacific (USP) laboratory for analysis.

For nutrient analysis, the Flow Injection Autoanalyser (FIA) located at the Chemistry Department of the USP in Suva, Fiji was used. Standards for calibration and methods used for analysis followed standard procedures (QuikChem Methods, 2003). Fecal coliform measurements were done whenever possible, depending on personnel and logistical factors. Standard procedures were followed (APHA-AWWA-WEF, 1998).

All statistical tests were conducted using SPSS 14.0 (Dytham, 2003).

Results

Nutrient variability, fecal coliform and water quality during dry weather

The dry weather water quality results for two examples of sampling events are presented in Fig. 2 and Table 1. Each nutrient value is the average from three replicate samples for that particular site on that day. The two sets of results were analysed statistically, to test if there were significant differences in nitrate and phosphate concentrations among the three categories of site (control, village and resort).

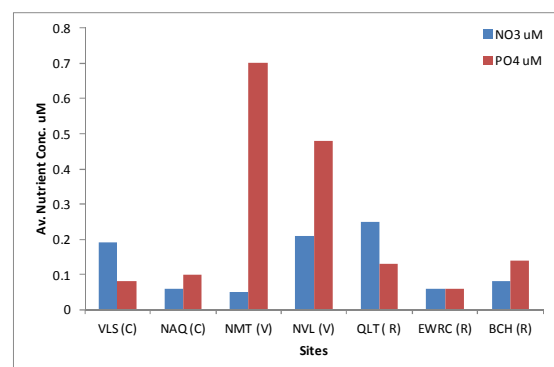


Figure 2: Nutrient concentrations at control (C) and impacted sites (V and R) on 13 May 2004, a dry weather dataset.

Sites	NO ₃ Av. uM	PO ₄ Av. uM	NO ₃ : PO ₄	Faecal coliform (c/100 ml)	Salinity (ppt)	Temperature (°C)
VLS (C)	0.9	0.34	2.65	28	36.5	25.6
NVL CRK	1.62	0.49	3.31	6700	0.5	24.0
NVL (V)	0.37	0.78	0.47	360	29.6	26.7
KMV CRK	2.62	1.30	2.02	No data	2.5	24.2
KMV (V)	0.22	0.90	0.24	140	26.0	26.0
NAQ (C)	0.28	0.88	0.32	9	35.5	25.7
NMQ CRK	0.61	1.31	0.47	19000	1.2	25.7
NMQ (V)	0.97	0.15	6.47	210	35.9	27.7
BCH (R)	0.06	0.95	0.06	23	35.2	27.8
WRC (R)	0.17	1.34	0.13	55	36.5	26.3

Table 1: Nutrient and fecal coliform concentrations for sites (including creeks) sampled on 11 August 2004, a dry weather dataset.

The results on 13 May 2004, showed that during dry weather, there is no significant variation in nitrate concentrations in the coastal waters near control, village and resort sites ($F_{2,19} = 0.127$, $p=0.88$). Phosphate concentrations however appeared to be highly variable, with the two village sites recording significantly higher phosphate concentrations ($F_{2,19} = 18.66$, $p=0.003$).

The results on 11 August 2004 (dry weather) included creek samples which had much higher nitrate and phosphate concentrations than the control, village and resort sites. One-way ANOVA for nitrate concentrations for the four site categories (C, V, R and CRK) gave a significant result ($F_{3,17} = 9.58$, $p=0.001$) but Least Significant Difference (LSD) post-hoc analysis revealed that there was no significant difference in nitrate levels between control and village sites ($p=0.74$); between control and resort sites ($p=0.52$); between village and resort sites ($p=0.65$) but creek nitrate results were significantly different from all the other three categories of sites ($p=0.001$, $p=0.001$, $p=0.002$).

Phosphate concentrations however did not vary significantly among the four categories of sites ($F_{3,19} = 1.76$, $p=0.19$) on this particular day. The results show that the creeks are major sources of nutrient and fecal coliform to the coastal waters, even on dry/sunny days. Temperatures are generally similar for all coastal sites, but slightly lower for creeks. Salinity (ppt) is lowest for the three creek sites (0.5, 2.5 and 1.2), but generally similar for the other coastal sites, ranging from 26.0 to 36.5 ppt.

Nutrient variability, during wet weather

Figure 3 and Table 2 show some of the results of water quality testing carried out during rainy/wet weather. The flushing effect of rainfall on nutrients, particularly nitrate is evident (Fig.3), and during these sampling events (June 4th and 8th 2004), the control sites (C) recorded the lowest nutrient concentrations compared to the village and resort sites.

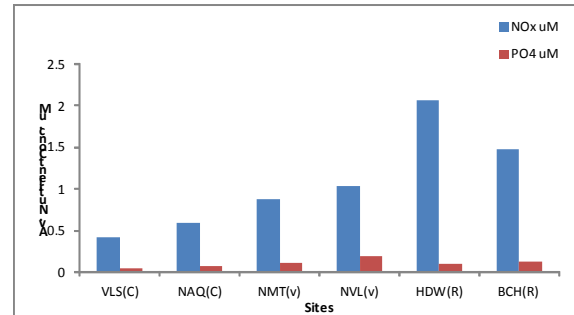


Figure 3: Nutrients concentrations for control (C) and impacted sites (R) and (V) sampled on 4 & 8 June 2004, a wet weather dataset.

The one-way ANOVA for nutrient concentrations (Fig.3) among the three categories of sites (C, V and R) showed that there were significant differences among control, village and resort sites with respect to nitrate ($F_{2,17} = 13.87$, $p=0.001$). LSD post-hoc tests revealed that the control sites differed significantly from village sites ($p=0.02$) and from resort sites ($p=0.001$). Village sites also differed significantly from resort sites ($p=0.02$) with respect to nitrate levels. For phosphate however, control sites differed significantly from village sites ($p=0.004$) but not from resorts ($p=0.205$). Village phosphate levels did not differ significantly from resort phosphate levels ($p=0.06$). These results showed the control sites Valase (VLS) and Naqau (NAQ) were still free of land-based nutrient sources during June 2004.

Table 2 again shows importance of creeks (CRK) as sources of nutrients and fecal coliform to the coastal waters along the Coral Coast. The two creeks recorded the highest concentrations of nitrate, phosphate, ammonia and fecal coliform on this particular day. Valase differed significantly from the other two control sites with respect to nitrate concentrations ($F_{2,6} = 193.53$, $p=0.00$) and ammonia concentrations ($F_{2,6} = 1.47E3$, $p=0.00$). There was no significant difference in the phosphate concentrations among the three control sites ($F_{2,6} = 1.13$, $p=0.38$). LSD post-hoc tests showed that Valase was significantly different from the other two control sites ($p=0.00$) whereas the two control sites (WVLS and CBN1) did not differ significantly from each other.

with regards to levels of nitrate ($p=0.43$) and ammonia ($p=0.13$).

Site	PO4 Av. µM	NH3 Av. µM	NO3 Av. µM	DIN Av. µM	DIN:PO4	Faecal coliform (c/100 mL)	Salinity (ppt)	Temp. (°C)	DO (mg/L)
VLS1 (C)	0.37	25.47	6.06	31.53	85.22	22	32.7	25.7	6.60
WVLS (C)	0.21	0.81	0.66	1.47	7.00	10	34.1	26.2	6.77
CBN1 (C)	0.04	1.25	0.26	1.51	37.75	10	36.0	26.2	7.40
CBC2 (CRK)	1.19	2.90	6.86	9.76	8.20	ND	15.0	24.9	7.40
VOC3 (CRK)	0.97	2.81	22.93	25.74	26.54	2855	0.1	24.5	6.90
BCH1 (R)	0.31	0.52	1.66	2.18	7.03	3040	35.6	27.2	7.90
HDW1 (R)	0.20	2.52	2.74	5.26	26.3	3	35.7	25.5	6.31
WRC (R)	0.33	0.17	0.21	0.38	1.15	24	35.6	27.1	7.5

Table 2: Nutrient and faecal coliform concentrations, and water quality for sites (including creeks) sampled on 27 April 2005, a wet weather dataset.

Comparing wet and dry weather nutrient levels to assess the significance of flush events

Three sites representing control (Valase), village (Namada) and resort (Hideaway) were treated separately, as these had sufficient data to run the statistical tests across seasons. Nitrate was significantly higher in the wet seasons at all three sites (Valase: Mann-Whitney $U = 3.00$, $p < 0.001$; Namada: $U = 8.00$, $p = 0.021$; Hideaway: $U = 0.00$, $p = 0.002$). In contrast, seasonal differences in phosphate were only observed at the Valase control site ($U = 8.00$, $p = 0.036$).

Date of Sampling	Season	Weather	PO4 Av. µM	NO3 Av. µM	NH3 Av. µM	DIN Av. µM	NO3: PO4 DIN : PO4*
2 Aug. '03	Cool/Dry	Dry	1.00	0.06	10.32	10.38	0.06 10.38*
10 Feb. '04	Hot/Wet	Wet	0.05	5.66	Nd	–	113.2
25 Mar '04	Hot/Wet	Dry	0.10	0.06	nd	–	0.6
13 May '04	Cool/Dry	Dry	0.13	0.25	nd	–	1.92
4 Feb. '05	Hot/Wet	Dry	0.33	0.54	1.36	1.90	1.64 5.76*
23 Mar '05	Hot/Wet	V. Wet	6.75	1.25	13.36	14.6	0.19 2.16*
27 April '05	Hot/Wet	V. Wet	0.18	0.05	0.13	0.18	0.28 1.00*
16 May '05	Cool/Dry	Dry	0.41	1.19	1.28	2.47	2.90 6.02*
Average			1.12	1.13	4.03	4.79	15.10 5.06*

Table 3: Temporal variation in nutrient concentrations for Qalito (QLT), a resort site.

Temporal variation in nutrient concentrations for a resort site – QLT

Table 3 shows temporal variation for a resort site close to Warwick Resort, Qalito. The results showed that there appears to be no clear association between season and nutrient levels, but nitrate and ammonia are generally boosted by wet weather conditions, as statistically shown for the June 2004 results. Ammonia concentrations dominated the total dissolved inorganic nitrogen (DIN) concentrations (Table 3). This showed the importance of ammonia as a form of nitrogen in the coastal waters along the Coral Coast. However, phosphate concentrations did not behave in as predictable a way as nitrate did. In some cases, rain elevated phosphate levels and in others, phosphate was actually reduced during heavy rain.

Temperature ranges are similar for the Hot and Wet Season and the Cool and Dry Season, unlike in temperate environments where temperature variation is vastly different from season to season. In the Coral Coast of Fiji, temperatures ranged from about 25°C to about 27°C in the Cool season, (Tables 1 & 2) and from about 28°C to about 31°C in the Hot season.

Discussion

The nutrient concentrations in the control and impacted sites along the Coral Coast are affected by weather and not so much the season. During dry weather, there is no significant difference among the sites, except where creeks discharge into the coastal waters, but during wet weather (rainfall > 25mm/day), the nitrate and ammonia levels are significantly higher in impacted sites compared to control sites. Elevated nutrient, especially nitrate and ammonia levels were associated with flushing out or pulse events during heavy rain and storm events. Phosphate levels are highly variable and do not behave in such a predictable way as the more mobile nitrate. When phosphate concentrations decrease with increased flow following heavy rainfall, the variation is considered evidence that the sources of phosphate are point sources such as sewage effluent, rather than diffuse sources such as agricultural sources (Jarvie et al., 2006).

The choice of 'control' sites turned out to be very limited; in fact, Valase was chosen as a control site initially (2004), but became another 'impacted' site as the ecotourism operation expanded with the construction of more thatched 'bures' or huts and houses (Valase) at the end of the first year of the study (Table 2). The land clearing and construction was for the expanding Valase resort as well as the

new Maui Resort next to Valase (Tamata, 2007). The change was reflected in the significantly higher nitrate and ammonia concentrations for Valase (VLS1) compared to the other two control sites (WVLS and CBN1). This is the sort of change that had been progressively occurring since the 1970s along the Coral Coast. A comparison of results from the current study with an earlier study (Mosley & Aalbersberg, 2003) showed that generally control sites recorded lower nutrient levels than village and resort sites. However, as shown in the case of Valase control site, the expansion of tourism operations underway plus the expansion of village and populations mean that in time, there will be no more 'control' sites and the whole Coral Coast coastline will be impacted by anthropogenic factors.

The rivers and creeks were significant sources of nutrients (and sewage pollution). Even during dry weather, the creeks contributed significant nutrient loading to the coastal waters. This points to the importance of monitoring catchment activities such as clearing of land and burning of vegetation for crop farming, use of creeks for washing and bathing, and having piggeries near creeks. Currently, there are collaborative activities among resort owners, local villagers, the government and some non-government organizations to address the listed activities that are potential sources of nutrients in the creeks and coastal waters. These include community awareness programs, re-location of piggeries and provision and maintenance of clean water supply for domestic usage.

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